Utah Geological Survey
a division of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Open-File Report 442
Interim Geologic Map of the Virgin Quadrangle

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP award number 03HQAG0096. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S Government.

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Scale 1:24,000

1 0.5 0 1 2 Miles

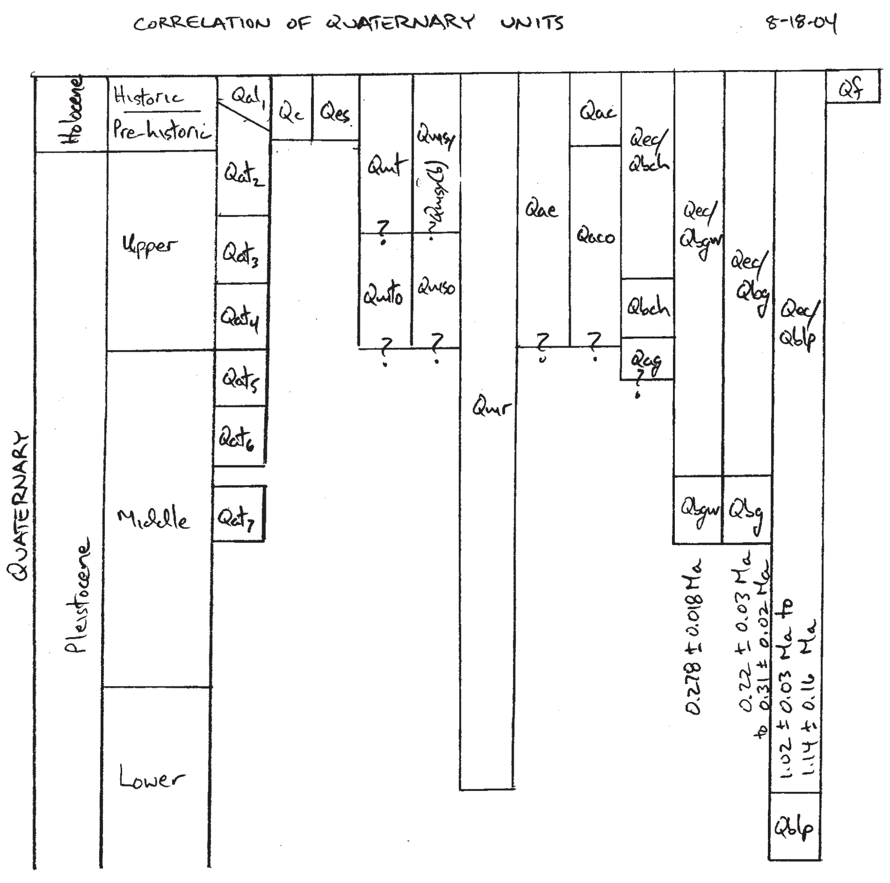
Project Manager: Robert F. Biek
Field mapping by author, 2003-2004.
Photogrammetry by Janice M. Hayden and Kent D. Brown, 2004.

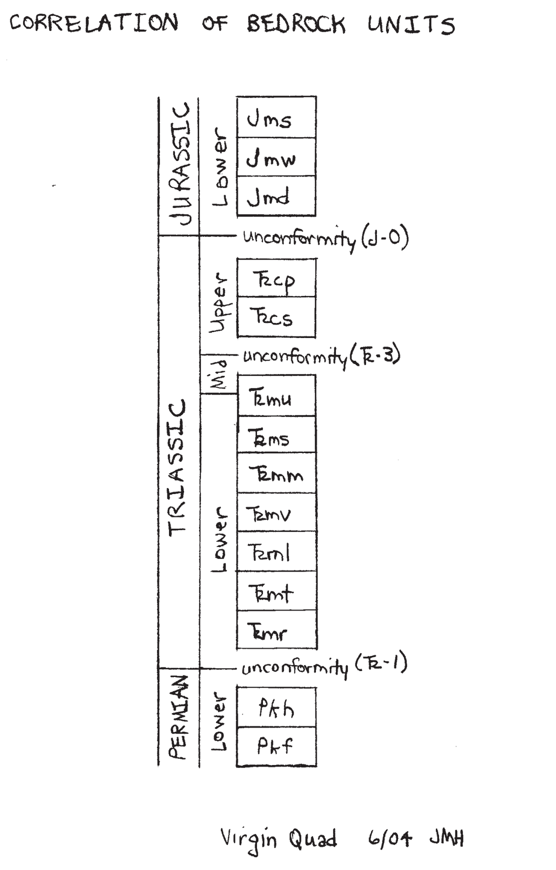
Interim Geologic Map of the Virgin Quadrangle, Washington County, Utah

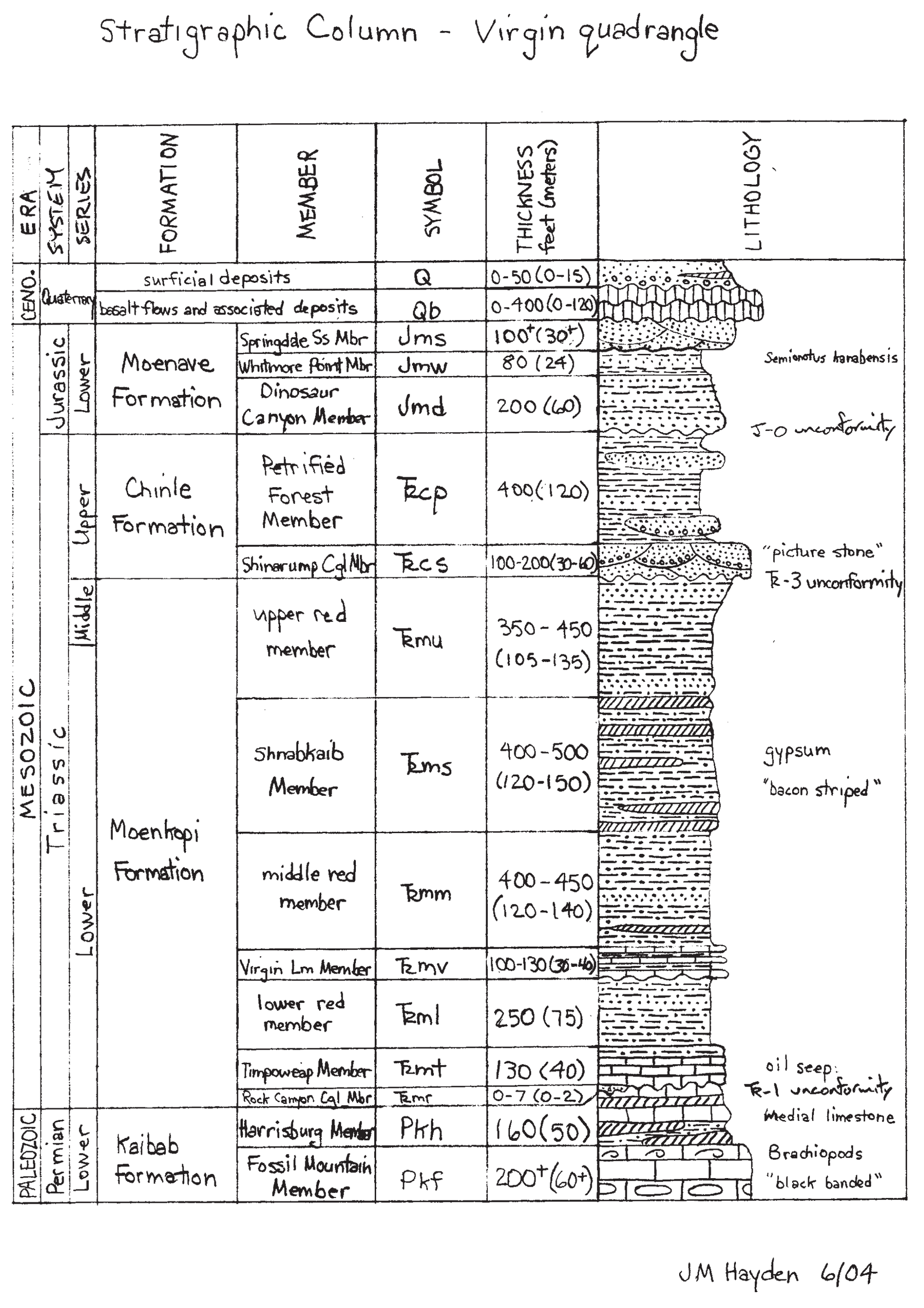
by

Janice M. Hayden,
Utah Geological Survey

2004







Geologic Map Symbols

- Contact
- Axial trace of syncline, dashed where approximately located
- Strike and dip of inclined bedding
- Approximate strike and dip of inclined bedding determined photogrammetrically
- Strike of near-vertical joint
- Pit - sand (s)
  gravel (g)
- Quarry – limestone
- Oil seep
- Breccia pipe
- Sample location and number
- Spring
- Structural contour drawn at base of Shinarump Conglomerate Member of the Chinle Formation (TRcs); dashed where projected. Contour interval 100 feet (30 m), datum is mean sea level.
- Petroleum exploration drill hole – plugged and abandoned. Well location data base provided by Utah Department of Natural Resources, Division of Oil, Gas and Mining.

Interim Geologic Map of the Virgin Quadrangle, Washington County, Utah

By

Janice M. Hayden

12-7-04

Utah Geological Survey Open-File Report 442

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Disclaimer

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Description of Map Units

QUATERNARY

Qf **Artificial fill deposits** (Historical) -- Artificial fill used to create small dams; consists of engineered fill and general borrow material; although only a few deposits have been mapped, fill should be anticipated in all built-up areas, many of which are shown on the topographic base map; 0 to 200 feet (0-60 m) thick.

Alluvial deposits

Qal1 **Alluvial-stream deposits** (Holocene) -- Moderately to well-sorted clay to fine gravel deposits in large active drainages; includes terraces up to 10 feet (3 m) above modern channels; mapped along the Virgin River and North Creek; includes both the active channel and modern terraces levels mapped to the east by Willis and others (2002); 0 to 30 feet (0-9 m) thick.

Qat2-Qat7
Alluvial-terrace deposits (Holocene to Middle Pleistocene) -- Moderately to well-sorted sand, silt, and pebble to boulder gravel that forms level to gently sloping surfaces above modern drainages; subscript denotes heights above active drainages; level 2 deposits include both "historic" and "settlement and late prehistoric" levels of Willis and others (2002) and are about 10 to 30 feet (3-9 m) above modern drainages; level 3 deposits are 30 to 90 feet (9-27 m), level 4 deposits are 90 to 140 feet (27-43 m), level 5 deposits are 140 to 190 feet (43-58 m), and level 6 deposits are 190 to 270 feet (58-82 m), and level 7 deposits are in excess of 300 feet (90 m) above modern drainages; deposited primarily in stream-channel and flood-plain environments; age of older terraces can be estimated using long-term incision rate of 1,300 feet per million years (400 m/my) derived from height of Lava Point flow above the Virgin River (see, for example, Willis and Biek, 2001); level 5, level 6, and level 7 deposits are likely Middle Pleistocene in age, whereas level 3 and level 4 deposits are likely Late Pleistocene in age; level 2 deposits are likely mostly Holocene in age, but may include both historical and latest Pleistocene sediments; 0 to 30 feet (0-9 m) thick.

Qag **Alluvial-gravel deposits** (Upper to Middle Pleistocene) -- Mappable in a few places beneath the Crater Hill lava flow; can be generally divided into two types: (1) subrounded to well-rounded, boulder- to cobble-size, abundant sandstone and occasional limestone clasts and subangular to subrounded basalt clasts in a muddy to sandy matrix; clast supported; imbricated; repeats above ground; mostly indurated; documents the location of the ancestral Virgin River bed; and (2) angular to subrounded, boulder- to cobble-size basalt clasts in a muddy to sandy matrix; matrix supported; no orientation to clasts; unsorted; partially indurated; probably deposited along the sloping edges of the ancestral Virgin River channel; 0 to 40 feet (0-12 m) thick.

Colluvial deposits

Qc **Colluvial deposits** (Holocene) -- Poorly to moderately sorted, angular to subrounded, clay- to boulder-sized, locally derived sediment deposited principally by slopewash and soil creep on moderate slopes; locally includes talus, alluvial, and eolian deposits; 0 to 30 feet (0-9 m) thick.

Eolian deposits

Qes **Eolian-sand deposits** (Holocene) -- Well- to very well sorted, very fine to medium-grained, well-rounded, mostly quartz sand; mapped near the town of Virgin; locally mixed with alluvial sand; deposited primarily on Timpoweap Member of Moenkopi Formation and alluvial-terrace deposits where the valley widens; 0 to 15 feet (0-4.5 m) thick.

Mass-movement deposits

Qmt, Qmto
Talus deposits (Holocene to Upper Pleistocene) -- Very poorly sorted, angular boulders with minor fine-grained interstitial sediment; deposited mostly by rock fall on and at the base of steep slopes; forms primarily from blocks that weather from the edges of lava flows, from the Shinarump Conglomerate Member that caps both Hurricane and Gooseberry Mesas, and from the Springdale Sandstone Member of the Moenave Formation that caps Smith Mesa; locally contain small landslide and slump deposits; may include and is gradational with older, mixed alluvial-colluvial deposits farther downslope; Qmt mantles steep slopes beneath cliffs and ledges, whereas Qmto mantles and armors a hillside where the cliff has receded; 0 to 20 feet (0-6 m) thick.

Qmsy, Qmso, Qmsy(b)
Landslide deposits (Holocene to Upper Pleistocene) -- Very poorly sorted clay- to boulder-size, locally derived debris in chaotic, hummocky mounds; form on steep slopes beneath lava flows, Springdale Sandstone Member of the Moenave Formation, and Shinarump Conglomerate Member of the Chinle Formation; basal slip surfaces develop mostly in Petrified Forest Member of the Chinle Formation and Shnabkaib and middle red members of the Moenkopi Formation; younger deposits (Qmsy) rest on modern hillsides whereas older deposits (Qmso) are chaotic bedrock debris armored by regolith and isolated from adjacent slopes due to slope retreat; Qmsy(b) consists of large blocks of Lava Point basaltic lava flow that collapsed and slid as softer underlying Petrified Forest Member of the Chinle Formation eroded (because of the gentle east dip of the underlying sedimentary rocks, the Lava Point flow has been undercut by the underlying Shinarump Conglomerate Member along its eastern margin, creating a straight cliff, but overlies the Petrified Forest Member along its western margin, resulting in large slide blocks); 0 to 100 feet (0-30 m) thick.

Qmr **Residual deposits of Lava Point flow** (Holocene to Lower Pleistocene) -- Residual lag of angular to subangular basalt blocks derived from the Lava Point flow; includes very rare blocks of sandstone, particularly in the northern and eastern portion of these deposits, possibly from the Springdale Sandstone Member of the Moenave Formation or Kayenta Formation – currently, sandstone cliffs of these rocks are approximately ¾ mile (1.2 km) east of the residual lag deposits, indicating significant slope retreat in the last one million years; also include one small area of subrounded to rounded sandstone and limestone pebbles and cobbles that could represent ancestral North Creek stream gravels; although Lava Point flow is virtually the only rock type seen in these deposits, nowhere is it clearly in place, suggesting that it probably represents a lag of basalt let down by erosion of underlying Petrified Forest Member of the Chinle Formation; thickness uncertain, but probably tens of feet thick.

Mixed-environment deposits

Qae **Mixed alluvial and eolian deposits** (Holocene to Upper Pleistocene) -- Moderately to well-sorted, clay- to sand-sized alluvial sediment that locally includes abundant eolian sand and minor gravel; exhibits stage II pedogenic carbonate development (Birkeland and others, 1991); mapped in Little Plain and Dalton Wash valleys in the southeast and northeast corners of the quadrangle; to 50 feet (0-15 m) thick.

Qac, Qaco
Mixed alluvial and colluvial deposits (Holocene to Upper Pleistocene) -- Poorly to moderately sorted, clay- to boulder-sized, locally derived sediment; gradational with alluvial, colluvial, and mixed alluvial and eolian deposits; younger material (Qac) is deposited in swales and minor drainages while older deposits (Qaco) form incised, inactive, gently sloping surfaces gradational with and downslope from colluvial and talus deposits; include terrace deposits too small to map separately; 0 to 20 feet (0-6 m) thick.

Basaltic lava flows and related deposits

Qbch, Qec/Qbch
Crater Hill lava flow and associated eolian deposits (Holocene to Upper Pleistocene) -- Medium-gray, weathering dark-brownish-gray to dark-brownish-black, olivine basalt lava flow (Qbch), as classified on the TAS diagram of LeBas and others (1986); vesicular to dense; locally jointed; upper surface generally has large arcuate pressure ridges; rubbly base where exposed; erupted from vent at Crater Hill cinder cone just east of quadrangle (Willis and others, 2002); flowed into, and overflowed, ancestral Scoggins and Coalpits Washes, then southward into the ancestral Virgin River, ponding, then continuing westward about 5 miles (8 km), into the Virgin quadrangle; lava dam created Lake Grafton in the Virgin River drainage and Coalpits Lake in Coalpits Wash (Hamilton, 1979, undated); Qec/Qbch denotes partial cover of eolian sand and pedogenic carbonate up to several feet thick; flow is 3 to 80 feet (1-24 m) thick, but locally up to feet (120 m) thick where it ponded in ancestral Virgin River channel (Willis and others,); base is about 125 feet (38 m) above modern Virgin River channel, but appears higher along State Highway 9 because the cliff face exposes a higher level of the dish-shaped flow (Willis and others, 2002); re-interpreted by Willis and others (2002) to represent a single (monocyclic) eruption rather than the multi-eruptive history proposed by Nielson (1977) and Downing (2000); Willis and others (2002) estimated this flow is about 100,000 years old, based on a long-term incision rate of 1,300 feet per million years (400 m/my) (Willis and Biek, 2001). Utah Geological Survey sample ZP-1501 in the Springdale West quadrangle yielded a very low precision whole-rock $^{40}Ar/^{39}Ar$ age of 0.10 ± 0.08 Ma.

Qbgw, Qec/Qbgw
Gould Wash lava flow and associated eolian deposits (Holocene to Middle Pleistocene) -- Dark-gray, very fine grained olivine basalt lava flow (Qbgw); abundant olivine phenocrysts; yielded an $^{40}Ar/^{39}Ar$ isochron age of 0.278 ± 0.018 Ma (Downing, 2000); erupted from two cinder cones just off the south edge of the quadrangle (Hayden, 2004); Qec/Qbgw denotes partial cover of eolian sand and pedogenic carbonate up to several feet thick; generally 20 to 30 feet (6-9 m) thick.

Qbg, Qec/Qbg
Grapevine Wash lava flow (Holocene to Middle Pleistocene) -- Medium-gray, weathering dark-brownish-gray to dark-brownish-black, fine-grained olivine basalt to basaltic trachyandesite lava flow, as classified on the TAS diagram of LeBas and others (1986); vesicular to dense; locally jointed; flow textures still evident on upper surfaces in places; rubbly base where exposed; erupted from several vents on the Lower Kolob Plateau, including Firepit Knoll and Spendlove Knoll cinder cones, about 6 miles (10 km) northeast of the quadrangle; five $^{40}Ar/^{39}Ar$ plateau ages range from 0.22 ± 0.03 Ma to 0.31 ± 0.02 Ma (Willis and Hylland, 2002); mapped along North Creek in the northeast corner of the quadrangle; 10 to 20 feet (3-6 m) thick.

Qblp, Qec/Qblp
Lava Point lava flow and associated eolian deposits (Holocene to Lower Pleistocene) -- Medium-gray, weathering to dark-brownish-gray to dark-brownish-black, phenocryst-poor, olivine basaltic trachyandesite to basaltic andesite lava flow; vesicular to dense; locally jointed; upper surface of flows generally strongly weathered; rubbly base where exposed; typically 20 to feet (6-12 m) thick; flowed down ancestral North Creek and now forms inverted valley that lies about 1,300 feet (400 m) above North Creek and the Virgin River; $^{40}Ar/^{39}Ar$ plateau ages range from 1.02 " 0.03 to 1.14 " 0.16 Ma (Biek, 2002; Willis and Hylland, 2002).

unconformity

JURASSIC
Moenave Formation

Jms **Springdale Sandstone Member of the Moenave Formation** (Lower Jurassic) -- Mostly pale-reddish-purple to pale-reddish-brown, moderately sorted, fine- to medium-grained, medium- to very thick bedded sandstone with planar and low-angle cross-stratification, and minor, thin, discontinuous lenses of intraformational conglomerate and thin interbeds of moderate-reddish-brown or greenish-gray mudstone and siltstone; has large lenticular and wedge-shaped, low-angle, medium-to large-scale cross-bedding; secondary color banding that varies from concordant to discordant with cross-bedding is common in the sandstone; weathers to rounded cliffs and ledges that cap Smith Mesa; contains locally abundant petrified and carbonized fossil plant remains; deposited in braided-stream and minor flood-plain environments (DeCourten,); incomplete thickness of about 100 feet (30 m); Willis and others (2002) reported a total thickness of 90 to 150 feet (27-46 m) in the Springdale West quadrangle to the east.

Jmw **Whitmore Point Member of the Moenave Formation** (Lower Jurassic) -- Interbedded, pale-reddish-brown, greenish-gray, and grayish-red mudstone and claystone, with thin-bedded, moderate-reddish-brown, very fine to fine-grained sandstone and siltstone; siltstone is commonly thin bedded to laminated in lenticular or wedge-shaped beds; claystone is generally flat bedded; contains several 3- to 18-inch-thick (7-48 cm), bioturbated, cherty, very light gray to yellowish-gray dolomitic limestone beds with algal structures, some altered to jasper, and fossil fish scales of *Semionotus kanabensis*; forms poorly exposed ledgy slope; upper, unconformable contact is placed at the base of the thick- to very thick bedded sandstone ledge of the Springdale Sandstone Member which creates a pronounced break in slope; deposited in low-energy lacustrine and fluvial environments (DeCourten, 1998); 80 feet (24 m) thick.

Jmd **Dinosaur Canyon Member of the Moenave Formation** (Lower Jurassic) -- Uniformly colored and interbedded, generally thin-bedded, moderate-reddish-brown to moderate-reddish orange, very fine to fine-grained sandstone, very fine grained silty sandstone, and lesser siltstone and mudstone; ripple marks and mud cracks common; forms ledgy slope; conformable and gradational upper contact placed at the base of the lowest light gray, thin-bedded, dolomitic limestone with algal structures; deposited on broad, low, stream-meander floodplain that was locally shallowly flooded by water (fluvial mud flat) (DeCourten, 1998); 200 feet (60 m) thick.

unconformity (J-0)

TRIASSIC
Chinle Formation

TRcp **Petrified Forest Member of the Chinle Formation** (Upper Triassic) -- Highly variegated, light-brownish-gray, pale-greenish-gray, to grayish-purple bentonic shale, mudstone, siltstone, and claystone, with lesser thick-bedded, resistant sandstone and pebble to small cobble conglomerate near base that is up to 30 feet (9 m) thick; clasts are primarily chert and quartzite; minor chert, nodular limestone, and very thin coal seams and lenses up to 0.5 inch (1 cm) thick; mudstone weathers to a "popcorn" surface due to expansive clays and causes road and building foundation problems; contains locally abundant, brightly colored fossilized wood including highly fractured logs up to 10 feet (3 m) long with a diameter of 1.5 feet (0.5 m); weathers as badlands; prone to landsliding, especially along steep hillsides; mostly slope forming; upper contact, poorly exposed due to slumping, is drawn at the obvious color change between the purplish mudstone below and the moderate-reddish-brown, fine-grained sandstone above; deposited in lacustrine, floodplain, and braided-stream environments (Dubiel, 1994); about 400 feet (120 m) thick.

TRcs **Shinarump Conglomerate Member of the Chinle Formation** (Upper Triassic) -- Varies from grayish-orange to moderate-yellowish-brown, medium- to coarse-grained sandstone with locally well-developed limonite bands ("picture stone" or "landscape rock") to moderate-brown pebble conglomerate with subrounded clasts of quartz, quartzite, and chert; mostly thick- to very thick bedded with both planar and low-angle cross-stratification; contains locally abundant, poorly preserved petrified wood fragments and common, highly fractured petrified logs several feet in length; forms the dark-brown to moderate-yellowish-brown cap rock of Goosberry and Hurricane Mesas; upper contact is placed between the yellowish-brown sandstone and pebbly sandstone of the Shinarump Conglomerate below and the base of the varicolored bentonitic mudstone beds of the Petrified Forest Member above; variable in composition and thickness because it represents stream-channel deposition over Late Triassic paleotopography (Dubiel,); generally ranges from 100 to 200 feet (30-60 m) thick.

unconformity (TR-3)

Moenkopi Formation

TRmu **Upper red member of the Moenkopi Formation** (Middle and Lower Triassic) -- Moderate-reddish-brown, thin-bedded siltstone and very fine grained sandstone with some thin gypsum beds and abundant discordant gypsum stringers; ripple marks common in the siltstone; forms a steep slope with a few sandstone ledges; locally includes 20-foot-thick (6 m), fine-grained, resistant sandstone near base; upper contact is placed at the slope and color changes between the ledges of moderate-reddish-brown siltstone and sandstone of the upper red member below and the cliff of moderate-yellowish-brown sandstone of the Shinarump Conglomerate Member above; deposited in coastal-plain and tidal-flat environments (Dubiel, 1994); 350 to 450 feet (105-135 m) thick.

TRms **Shnabkaib Member of the Moenkopi Formation** (Lower Triassic) -- Light-gray to pale-red, gypsiferous siltstone with bedded gypsum and several thin interbeds of dolomitic, unfossiliferous limestone near the base; upper part is very gypsiferous and weathers to a powdery soil commonly covered by microbiotic crust; forms ledge-slope "bacon-striped" topography; prone to landsliding; upper gradational contact, marked by a prominent color change and lesser slope change, is placed at the top of the highest lighter colored, thick gypsum bed, above which are the steeper sloped, laminated to thin-bedded, moderate-reddish-brown siltstone and sandstone beds of the upper red member; deposited on broad coastal shelf of very low relief where minor fluctuations in sea level produced interbedding of evaporites and red beds (Dubiel, 1994); 400 to 500 feet (120-150 m) thick.

TRmm **Middle red member of the Moenkopi Formation** (Lower Triassic) -- Interbedded moderate-red to moderate-reddish-brown siltstone, mudstone, and thin-bedded, very fine grained sandstone with thin interbeds and veinlets of greenish-gray to white gypsum; forms slope with several ledge-forming gypsum beds near base; upper contact is placed at the base of the first thick gypsum bed where the moderate-reddish-brown siltstone below gives way to banded, greenish-gray gypsum and pale-red siltstone above; deposited in tidal-flat environment (Dubiel, 1994); to 450 feet (120-140 m) thick.

TRmv **Virgin Limestone Member of the Moenkopi Formation** (Lower Triassic) -- Three distinct medium-gray to yellowish-brown limestone ledges interbedded with nonresistant, moderate-yellowish-brown, muddy siltstone, pale-reddish-brown sandstone, and light-gray to grayish-orange-pink gypsum; limestone beds are typically 5 to 10 feet (1.5-3 m) thick and contain five-sided crinoid columnals and *Composita* brachiopods (Billingsley, 1992); upper contact is drawn at the top of the highest limestone bed; deposited in shallow-marine environment (Dubiel,1994); to 130 feet (30-40 m) thick.

unconformity

TRml **Lower red member of the Moenkopi Formation** (Lower Triassic) -- Moderate-reddish-brown siltstone, mudstone, and fine-grained, slope-forming sandstone; locally, the lower part is irregularly colored yellowish-orange; generally calcareous and has interbeds and stringers of gypsum; ripple marks and small-scale cross-beds are common in the siltstone; upper contact drawn at the color change from moderate-reddish-brown siltstone of the lower red member to moderate-yellowish-brown, muddy siltstone, usually about 3 feet (1 m) thick, which underlies the base of the first limestone ledge of the Virgin Limestone Member; deposited in tidal-flat environment (Dubiel, 1994); about 250 feet (75 m) thick.

TRmt **Timpoweap Member of the Moenkopi Formation** (Lower Triassic) -- Lower part is light-gray to grayish-orange, thin- to thick-bedded limestone and cherty limestone that weathers light-brown with a rough, "meringue-like" surface due to blebs of chert; contains gastropods, brachiopods, and rare ammonites; some beds include euhedral pyrite crystals up to 1/4 inch (1 cm); upper part is grayish-orange, thin- to thick-bedded, slightly calcareous, very fine grained sandstone with thin-bedded siltstone and mudstone intervals; weathers yellowish-brown; significant petroliferous outcrops and oil seeps in Timpoweap Canyon of the Virgin River and in its tributaries to the north where the upper Timpoweap crops out (Blakey, 1979); producing interval of Virgin oil field; forms ledges or low cliff; upper contact placed at the color change from grayish-orange sandstone of the Timpoweap Member below to the moderate-reddish-brown siltstone of the lower red member above; active dimension stone quarries; deposited in shallow, north-trending marine trough, filling paleotopography on top of the Kaibab Formation (Nielson, 1981); thickness approximately 130 feet (40 m).

TRmr **Rock Canyon Conglomerate Member of the Moenkopi Formation** (Lower Triassic) – Regionally consists of two main rock types: (1) a pebble to cobble, clast-supported conglomerate with subrounded to rounded chert and minor limestone clasts derived from Harrisburg strata, which was deposited as channel fill in paleovalleys (Nielson, 1991) and as a thinner and sandier breccia-to-conglomerate fill above breccia pipe collapse features in the Harrisburg Member of the Kaibab Formation, and (2) a thin breccia or regolith deposit (Nielson, 1991) on Harrisburg strata; in this quadrangle, only the thin breccia of type (2) is present in a few places along the Virgin River in the west half of the quadrangle; upper gradational contact is placed at the base of the first laterally extensive yellowish-brown limestone of the Timpoweap Member; 0 to 7 feet (0-2 m) thick.

Unconformity (TR-1)

PERMIAN
Kaibab Formation

Pkh **Harrisburg Member of the Kaibab Formation** (Lower Permian) -- Interbedded thin- to very thick bedded gypsum, gypsiferous mudstone, and limestone, some of which contains chert; laterally variable; mostly slope-forming, but includes a resistant, cliff- and ledge-forming medial white chert and limestone interval; gypsum dissolution causes separation of limestone blocks along joints creating an area locally called "the cracks" along the Virgin River canyon in SE1/4SE1/4 section 19 and NE1/4NE1/4 section 30, T. 41 S., R. 12 W.; one breccia pipe collapse feature is mapped in NW1/4SE1/4 section 19, T. 41 S., R. 12 W. (Wenrich and Huntoon, 1989); upper unconformable contact with the Rock Canyon Conglomerate Member, or where not present the Timpoweap Member of the Moenkopi Formation, is usually within a ledge or cliff-forming interval and difficult to pick out, but generally, irregularly bedded Harrisburg Member below weathers grayer and more blocky than thin, gently undulating Timpoweap Member above that weathers more brown and platy; Rock Canyon Conglomerate, if present, is the thin interval of conglomerate and/or breccia tucked in between these two similar lithologies; deposited in a complex sequence of sabkha and shallow-marine environments (Nielson, 1981); 160 feet (50 m) thick.

Pkf **Fossil Mountain Member of the Kaibab Formation** (Lower Permian) -- Light-gray, thick- to very thick bedded, planar-bedded, laterally consistent, cherty limestone and fossiliferous limestone; whole silicified brachiopods abundant near top; "black-banded" due to abundant reddish-brown, brown, and black chert; forms prominent cliff; upper conformable contact drawn at the break in slope between the limestone cliff of Fossil Mountain Member and the gypsiferous mudstone and gypsum slope of the Harrisburg Member; deposited in shallow-marine environment (Nielson, 1986); 208 to 286 feet (63-87 m) thick in the Hurricane quadrangle to the west (Nielson,1981), but only about 200 feet (60 m) exposed within the quadrangle.

Subsurface Unit

Pzu Paleozoic, undivided -- shown on cross section only.

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Virgin Oil Field

With the drilling of the first well in 1907, the Virgin oil field has the distinction of being the oldest oil field in Utah (Heylmun, 1993). The discovery well was probably drilled in an attempt to locate the down-dip source of the oil seeps observed in Timpoweap Canyon and its tributaries, about 4 miles (6 km) southwest of the field (Richardson, 1908). The trapping mechanism is generally believed to be stratigraphic due to the lack of significant structural closure, the depressured nature of the field at discovery, interpretations of the depositional environment, the variability of porosity and permeability over relatively short distances, and the differences in pay thickness which varies from 1 to 12 feet (0.3-3 m) but averages only 4 feet (1.2 m) thick (Blakey, 1979). Production is primarily from the Timpoweap Member of the Moenkopi Formation (Gregory, 1950) with a possible contribution from the subjacent Kaibab Formation (Brandt, 1989). Productive depths range from 475 to 800 feet (145-244 m) with an average of 550 feet (168 m) (Bahr, 1963). The brown to black oil ranges from 22° API sour crude at the shallow south end of the field, to 32° API sweet crude at the deeper north end and has a mixed paraffin-asphalt base (Heylmun, 1993). Field development and production occurred intermittently with the last production report dated April 1985 (Christopher J. Kierst, Division of Oil, Gas and Mining, verbal communication, October 29, 2004). Cumulative production of over 206,000 barrels of oil is estimated since production records were not preserved prior to 1927 (Christopher J. Kierst, verbal communication, October 29, 2004). The productive area included about 200 acres (0.8 km²) (Heylmun, 1993). All known wells have now been plugged and abandoned (Christopher J. Kierst, verbal communication, October 29,).

Table 1. Whole-rock chemical analysis.

Sample No.	Flow	Longitude	Latitude	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	TOTAL	Ba	Cs	Hf	La	Nb	Rb	Sr	Ta	Y	Zr
VR41-01	Qblp	113 08' 48.4"	37 12' 40.6"	15.67	7.75	<0.01	10.00	2.10	7.41	0.15	4.19	0.77	49.75	1.96	0.01	99.76	841	1	6	49	30	18	1025	3	27	258

Notes: Sample location based on North American Datum of 1927.
LOI = loss on ignition.
Analysis performed by ALS Chemex Labs, Inc., Sparks, NV.
Major oxides in weight percent by XRF; minor and trace elements by ICP-MS in ppm.